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DESIGN OF RECTANGULAR WAVEGUIDE ARRAYS FOR GENERATING LOW SIDE LOBES

P. RAJYALAXMI[1] & M SURENDRA KUMAR[2]

[1]M.TECH Scholar, Department of ECE, KLR College of Engineering & Technology,
Paloncha, Khammam (Dist), Telangana, India

[2]Professor & Principal, Department of ECE, KLR College of Engineering & Technology,
Paloncha, Khammam (Dist), Telangana, India

ABSTRACT

Antenna or Aerial is a transducer which converts one form energy into another form of energy, like that antenna is an electrical device which converts electric power into electromagnetic waves and vice versa. Single antenna element characteristics are not sufficient in wireless communication and radar applications. In view of this array antenna system is preferred in the wireless communication and radar applications.

An **antenna array** is group of antennas connected and arranged in linear &planar structures to form a single antenna that is able to produce radiation patterns not produced by individual antennas. They provide a solution to the problems caused by single antennas. In general, it is required to design an array to produce a pattern with narrow beam width, low side lobes and decaying minor lobes. Antenna array synthesis is a technique which determines input or source distribution for a specified radiation pattern. In this Design of Rectangular Waveguide Arrays for Generating Low side Lobes some standard amplitude distribution techniques are used. Some of those techniques are Uniform Amplitude distribution, Circular Amplitude distribution, Parabolic Amplitude distribution. If minor lobe decays the total energy concentrate only on main lobe and having narrow beam width. The above three amplitude distributions are used to produce required beams and gain for wireless and radar communication.

KEYWORDS: Antenna Array, Array Synthesis, Amplitude Distributions, Multiplication Pattern

INTRODUCTION

An **antenna array** is group of antennas connected and arranged in a regular structure to form a single antenna that is able to produce radiation patterns not produced by individual antennas. An important characteristic of an array is change of its radiation pattern in response to different excitations of its antenna elements [1].

An important characteristic of an array is change of its radiation pattern in response to different excitations of its antenna elements. Unlike a single antenna whose radiation pattern is fixed, an antenna array's radiation pattern, called the "Array pattern", can be changed upon exciting its elements with different currents (both current magnitudes and current phases). However, increasing the size of the array will eventually produce grating lobes - undesirable directions of maximum radiation. The overall radiation pattern of an array is determined by this array factor combined with the radiation pattern of the antenna element. The overall radiation pattern results in a certain directivity and thus gain linked through the **efficiency** with the directivity. Directivity and gain are equal if the efficiency is 100%. The radiated field strength at a certain point in space, assumed to be in the far field, is calculated by adding the contributions of each element to the total

radiated fields. If the elements are identical (antenna array made up of all the same type of antennas), and have the same physical orientation (all point or face the same direction), then the radiation (or reception) pattern for an antenna array is simply the Array Factor multiplied by the radiation pattern $R(\theta,\phi)$. This concept is known as **Pattern multiplication** [4]**.** Arrays can be designed to radiate in either **Broadside** i.e. radiation perpendicular to array orientation or **End fire** i.e. radiation in the same direction as the array orientation.. In antenna array synthesis, input or source distribution is determine for a specified radiation pattern. It is physically realizable source distribution for fixed spacing and phase distribution. In general, it is required to design an array to produce a pattern with narrow beam width, low side lobes and decaying minor lobes. The main task is to find out the antenna configuration, its geometrical dimensions & excitation or input or source distribution [4].

AMPLITUDE DISTRIBUTIONS AND DESIGN

The array factor depends on the number of elements, the element spacing, amplitude and phase of the applied signal to each element. The number of elements and the element spacing determine the surface area of the overall radiating structure. The standard amplitude distributions in array synthesis are Uniform amplitude distribution, Circular amplitude distribution & Parabolic amplitude distribution [4].

Uniform Amplitude Distribution: It is represented by $A(x)=C$ =constant

Circular Amplitude Distribution: It is represented by $A(x)=\sqrt{1-\left(\frac{2x}{l}\right)^2}$ Where l = length of array. This is shown in below Figure with x variation from $\frac{-l}{2}$ to $\frac{l}{2}$

Parabolic Amplitude Distribution: This is shown in below Figure. It is represented by $A(x)=\left[1-\left(\frac{2x}{l}\right)^2\right]$ Where l = length of array. This is shown in below Figure with x variation from $\frac{-l}{2}$ to $\frac{l}{2}$

The radiation pattern of by using Uniform amplitude distribution, Circular amplitude distribution & Parabolic amplitude distributions are obtained by the equation is

$$E(u)=\sum_{n=1}^{N} a(x_n)e^{j\frac{2\pi N u x_n}{2}}$$

Where $\mathrm{x_n}=\frac{\mathrm{2n-1-N}}{\mathrm{N}}=$ location of n^{th} element.; N=number of elements in array

$a(x_n)=$ Amplitude distribution; $u=\sin\theta$

Waveguide: The open-ended waveguide is a rectangular waveguide, open at its end and terminated in a large ground plane.

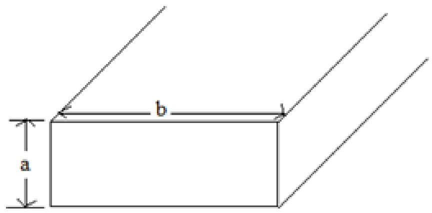

Figure 1: Rectangular Waveguide

With the origin of coordinate taken at the middle of a transverse cross section rather than a corner, the electric field of the incident TE_{10} mode can be expressed in the form [11] .

$$E^1{}_y = C\cos\frac{\pi x}{a} e^{j(\omega t-\beta_{10}z)}$$

It will be assumed that these two fields comprise the bulk of E_T in the aperture. Then

$$E_T = \mathbf{1}_y C^1 \cos\frac{\pi\xi}{a}$$

$$\Im_\theta(\theta,\phi) = 2\mu_0{}^{-1}C^1\cos\theta\cos\phi\int_{-a/2}^{a/2}\int_{-b/2}^{b/2}\cos\frac{\pi\xi}{a}e^{jk\sin\theta(\xi\cos\phi+\eta\sin\phi)}d\xi d\eta$$

$$\Im_\theta(\theta,\phi) = -4\pi\mu_0{}^{-1}abC^1\sin\phi\frac{\cos(\pi X)}{\pi^2-4(\pi X)^2}\frac{\sin(\pi Y)}{\pi Y} \quad (1)$$

in which $X = \frac{a}{\lambda}\sin\theta\cos\phi$ and $Y = \frac{b}{\lambda}\sin\theta\sin\phi$

It follows that $E_\theta = -k\Im_\phi$ and $E_\phi = k\Im_\theta$, with k a common multiplier that include the outgoing spherical wave factor. Therefore in the XZ-plane, there is only an $E\phi$ component, given in normalized form by

$$E_\phi(\theta) = \pi^2\cos\theta\frac{\cos\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\pi^2-4\left(\frac{\pi a}{\lambda}\sin\theta\right)^2} \quad (2)$$

In the $YZ-$plane $(\phi = 90^0, 270^0)$, there is only an E_θ component, given by

$$E_\theta(\theta) = \frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi b}{\lambda}\sin\theta}$$

Polar plots of these two principal-plane field pattern, for typical values $\left(a/\lambda\right)$=0.7 and $\left(b/\lambda\right) = 0.35$ are shown in

below figure. Plots for intermediate $\phi -$ cuts shows a smooth transition, with net polarization always parallel to the YZ-plane [11].

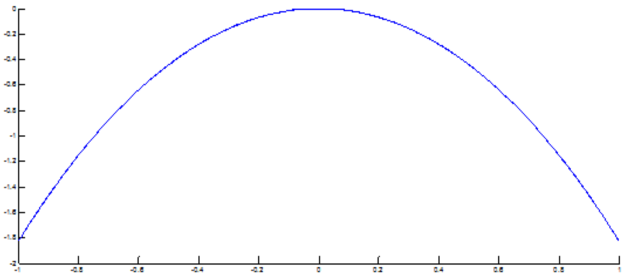

Figure 2: Normalized E-Field Pattern of an Open-ended Rectangular Waveguide with Large Ground Plane For $a = 0.7\lambda \,\&\, b = 0.35\lambda$

Pattern Multiplication

Pattern multiplication is defined that resultant pattern is equal to the array factor multiplied with the element pattern i.e, $E(\theta)_{resultant}$ = Element Pattern× Array Factor

RESULTS

The Uniform, Circular, Parabolic Amplitude distributions are shown in below figures. Those amplitude distributions are used in decaying the side lobes to the required level. These are used for practical element like wave guide.The normalized form of Rectangular waveguide can be indicated by equation (2). The resultant radiation patterns of Rectangular waveguide with amplitude distributions are presented by using pattern multiplication. The comparison of Amplitude distributions & Rectangular waveguide with Amplitude distributions represented are in Table1 & Table2 for N=10, 20, 40, 100.The isotropic antenna with standard amplitude distributions first side lobe level is approximately equal to the Rectangular waveguide with amplitude distribution first side lobe level. By using these amplitude distribution we proved low side lobes, Narrow beam width & high gain. Then this type of array antenna system is preferred in the wireless communication and radar applications.

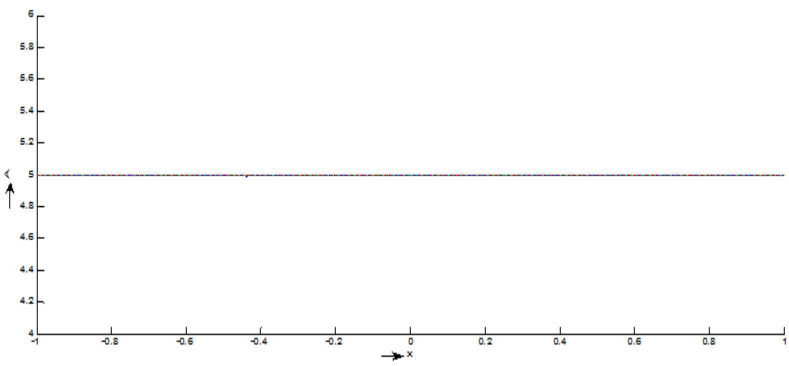

Figure 3: Uniform Amplitude Distribution

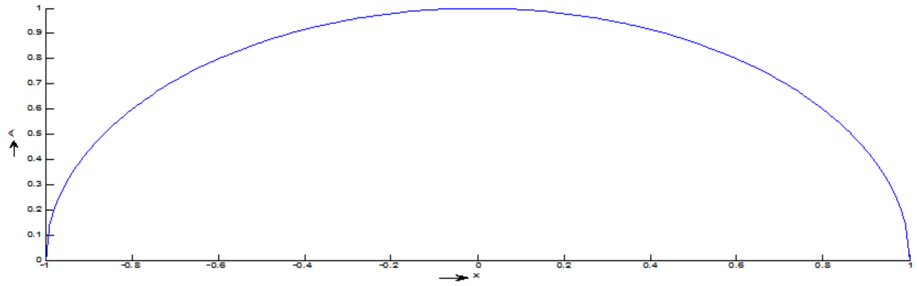

Figure 4: Circular Amplitude Distribution

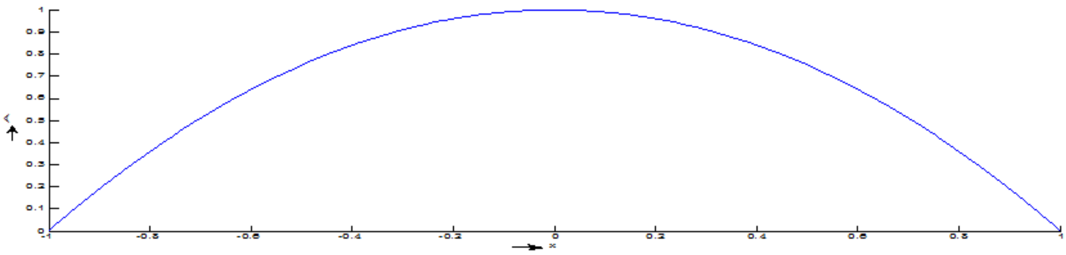

Figure 5: Parabolic Amplitude Distribution

Table1: Uniform, Circular, Parabolic Amplitude Distribution Characteristics by Changing N Value

S. No	No. of Elements	Uniform Amplitude Distribution		Circular Amplitude Distribution		Parabolic Amplitude Distribution	
		Beam Width	Fsll	Beam Width	Fsll	Beamwidth	Fsll
1	5	0.3	-12.80	0.3	-17.31	0.3	-21.20
2	10	0.2	-12.97	0.25	-17.80	0.25	-21.86
3	20	0.2	-13.19	0.2	-17.66	0.25	-21.44
4	30	0.15	-13.36	0.2	-17.63	0.2	-21.36
5	40	0.15	-13.26	0.15	-17.61	0.2	-21.32
6	60	0.1	-13.26	0.15	-17.62	0.15	-21.38
7	100	0.1	-13.40	0.1	-17.63	0.1	-21.30
8	120	0.05	-13.29	0.05	-17.58	0.05	-21.30

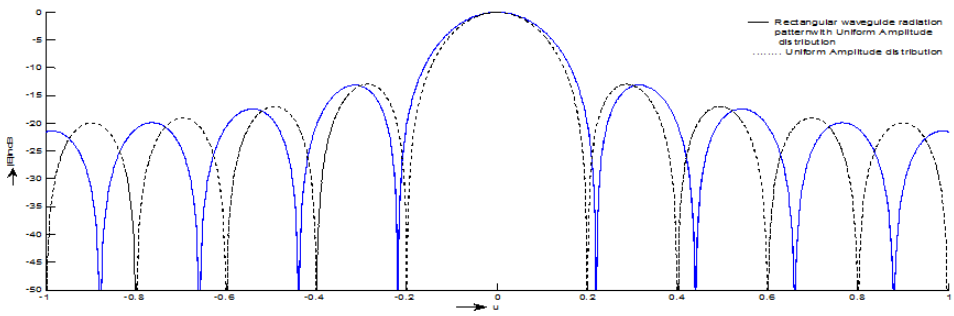

Figure 6: Rectangular Waveguide Radiation Pattern of an Array of N=10 Elements Using Uniform Amplitude Distributions

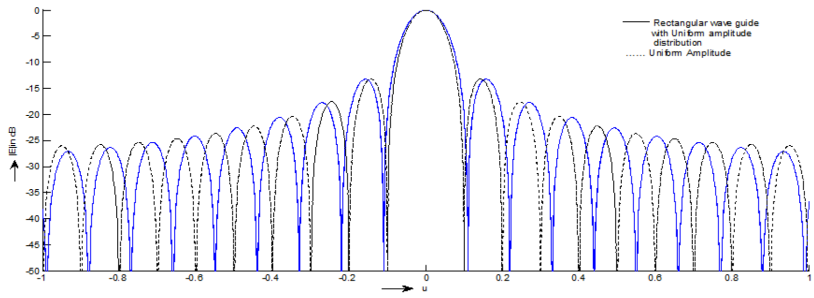

Figure 7: Rectangular Waveguide Radiation Pattern of an Array of N=20 Elements Using Uniform Amplitude Distributions

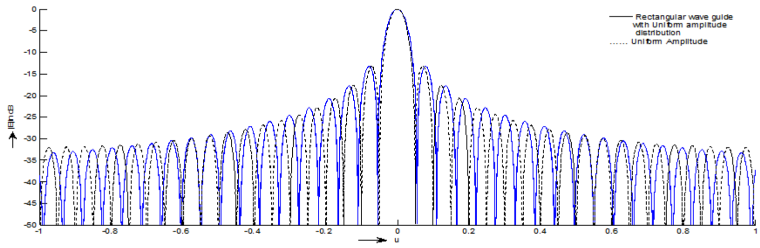

Figure 8: Rectangular Waveguide Radiation Pattern of an Array of N=40 Elements Using Uniform Amplitude Distributions

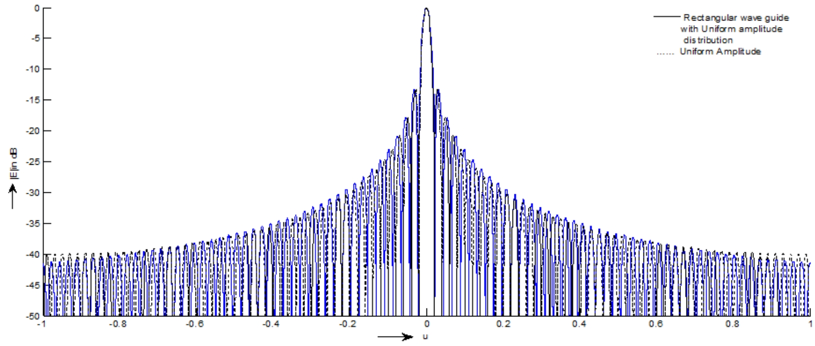

Figure.9: Rectangular Waveguide Radiation Pattern of an Array of N=100 Elements Using Uniform Amplitude Distributions

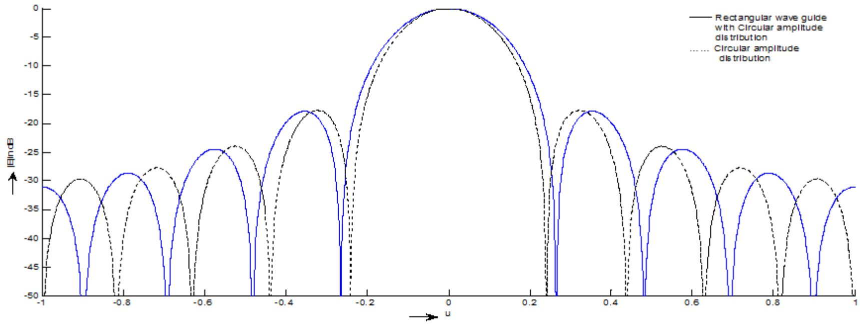

Figure 10: Rectangular Waveguide Radiation Pattern of an Array of N=10 Elements Using Circular Amplitude Distributions

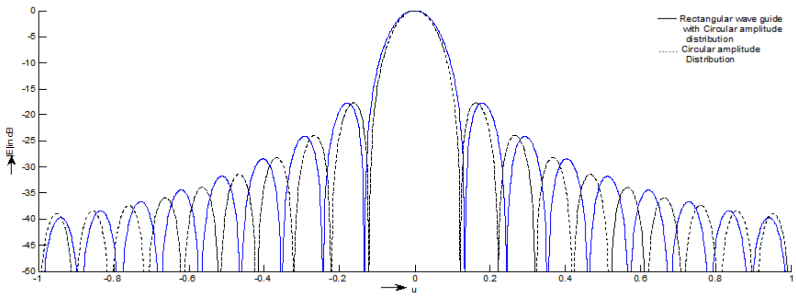

Figure 11: Rectangular Waveguide Radiation Pattern of an Array of N=20 Elements Using Circular Amplitude Distributions

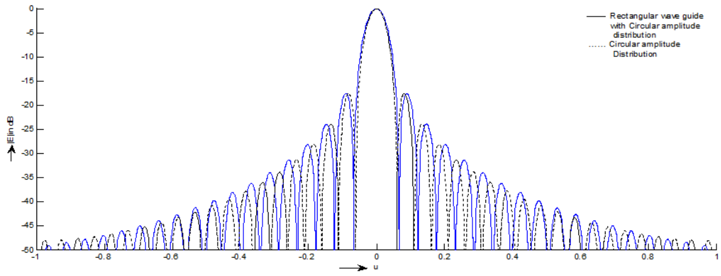

Figure 12: Rectangular Waveguide Radiation Pattern of an Array of N=40 Elements Using Circular Amplitude Distributions

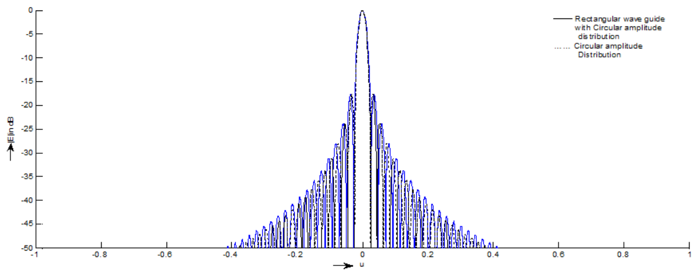

Figure 13: Rectangular Waveguide Radiation Pattern of an Array of N=100 Elements Using Circular Amplitude Distributions

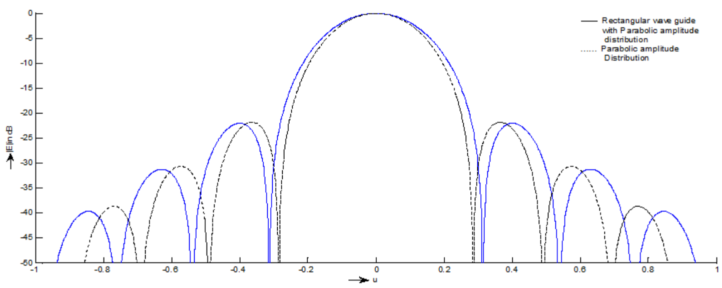

Figure 14: Rectangular Waveguide Radiation Pattern of an Array of N=10 Elements Using Parabolic Circular Amplitude Distributions

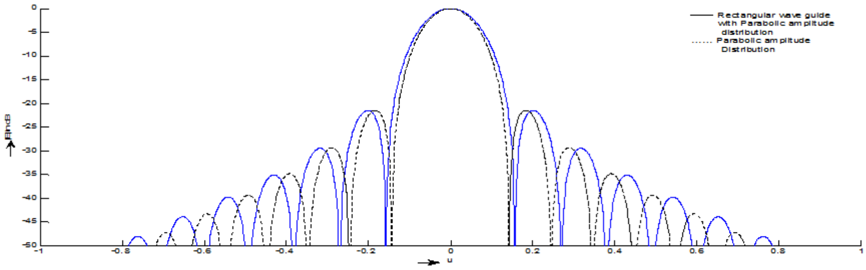

Figure 15: Rectangular Waveguide Radiation Pattern of an Array of N=20 Elements Using Parabolic Circular Amplitude Distributions

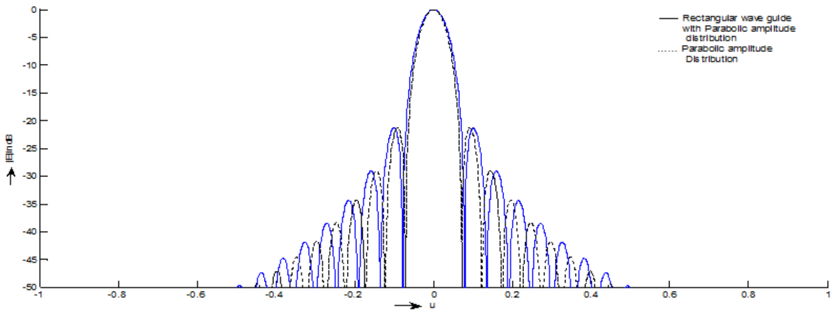

Figure 16: Rectangular Waveguide Radiation Pattern of an Array of N=40 Elements Using Parabolic Circular Amplitude Distributions

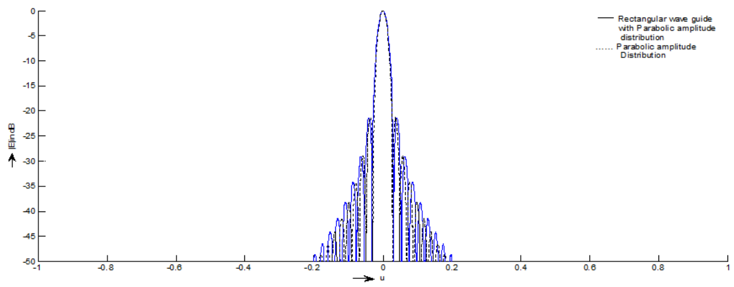

Figure 17: Rectangular Waveguide Radiation Pattern of an Array of N=100 Elements Using Parabolic Circular Amplitude Distributions

Table 2: Rectangular Waveguide Array Characteristics by Changing N Value

S. No	Number of Elements	Uniform Amplitude Distribution		Circular Amplitude Distribution		Parabolic Amplitude Distribution	
		Beam Width	Fsll	Beam Width	Fsll	Beam Width	Fsll
1	10	0.3	-13.11	0.3	-17.92	0.3	-22.12
2	20	0.25	-13.24	0.25	-17.72	0.25	-21.55
3	30	0.2	-13.43	0.25	-17.66	0.2	-21.38
4	40	0.15	-13.44	0.2	-17.62	0.2	-21.40
5	60	0.15	-13.46	0.15	-17.94	0.15	-21.32
6	80	0.15	-13.42	0.1	-17.62	0.1	-22.83
7	100	0.1	-13.46	0.1	-17.42	0.1	-22.39
8	120	0.05	-13.29	0.05	-17.10	0.05	-22.30

CONCLUSIONS

To reduce side lobes level we use Amplitude distribution methods those are Uniform, Circular & Parabolic amplitude distribution. By Comparing Uniform, Circular, Parabolic amplitude distribution we observe that the first side lobe level of Uniform Amplitude distribution is high comparing with other amplitude distribution radiation patterns & beam width is less comparing with parabolic & Circular amplitude distributions. The amplitude distributions are used in practical antenna elements i.e., in Rectangular Waveguide. The normalized form of Rectangular waveguide can be indicated by equation (2). The resultant Rectangular waveguide Radiation Pattern of an array of N elements using Parabolic Circular amplitude distributions are shown in above figures from 6 to 23. Uniform, Circular, Parabolic Amplitude distribution characteristics by changing N value & Rectangular Waveguide Array characteristics by changing N value represented are in Table 1 & Table 2 for N=10, 20, 40, 100.

Then we use these standard amplitude distributions to implement Practical elements. By using this amplitude distribution it provides low side lobe level, Narrow beam width & high gain. This type of array antenna system is preferred in the wireless communication and radar applications.

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AUTHORS BIO- DATA

Ms. P. Rajyalakshmi: received her B. Tech From JNTU-Hyderabad with Distnction, Presently pursuing M. Tech , from KLR College of engineering and Technology-Paloncha affiliated to Jntu-Hyderabad.

Dr. M. Surendra Kumar received his B.Tech from Nagarjuna University and M. Tech, Ph.D from Andhra University. He has 18 years of teaching experience. He published 23 technical papers in National and International conferences and journals. His fields of interest are Antennas and wave propagation, Microwave engineering and Radar Engineering. Presently he is working as a Principal in K L R College of Engineering & Technology- Paloncha, Khammam -Dist, Telangana